

# CLIMATE CHANGE CERTAINTIES AND UNCERTAINTIES

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*<http://www.ecd.bnl.gov/steve>*

# OUTLINE

Earth's energy balance

    Perturbations

Climate forcing and response

    Earth's climate sensitivity

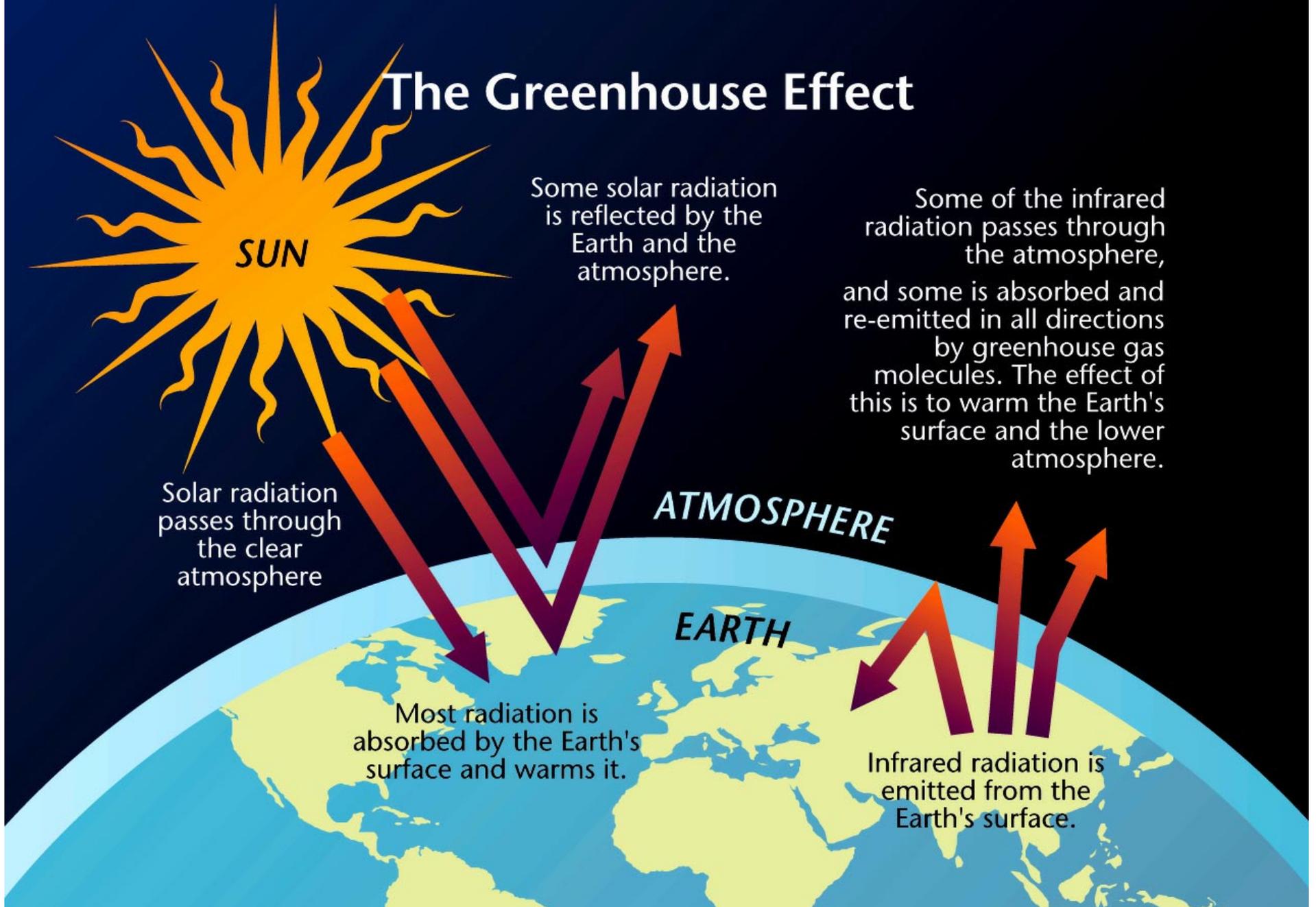
Influence of aerosols

Uncertainty in climate forcing and its implications

Looking to the future

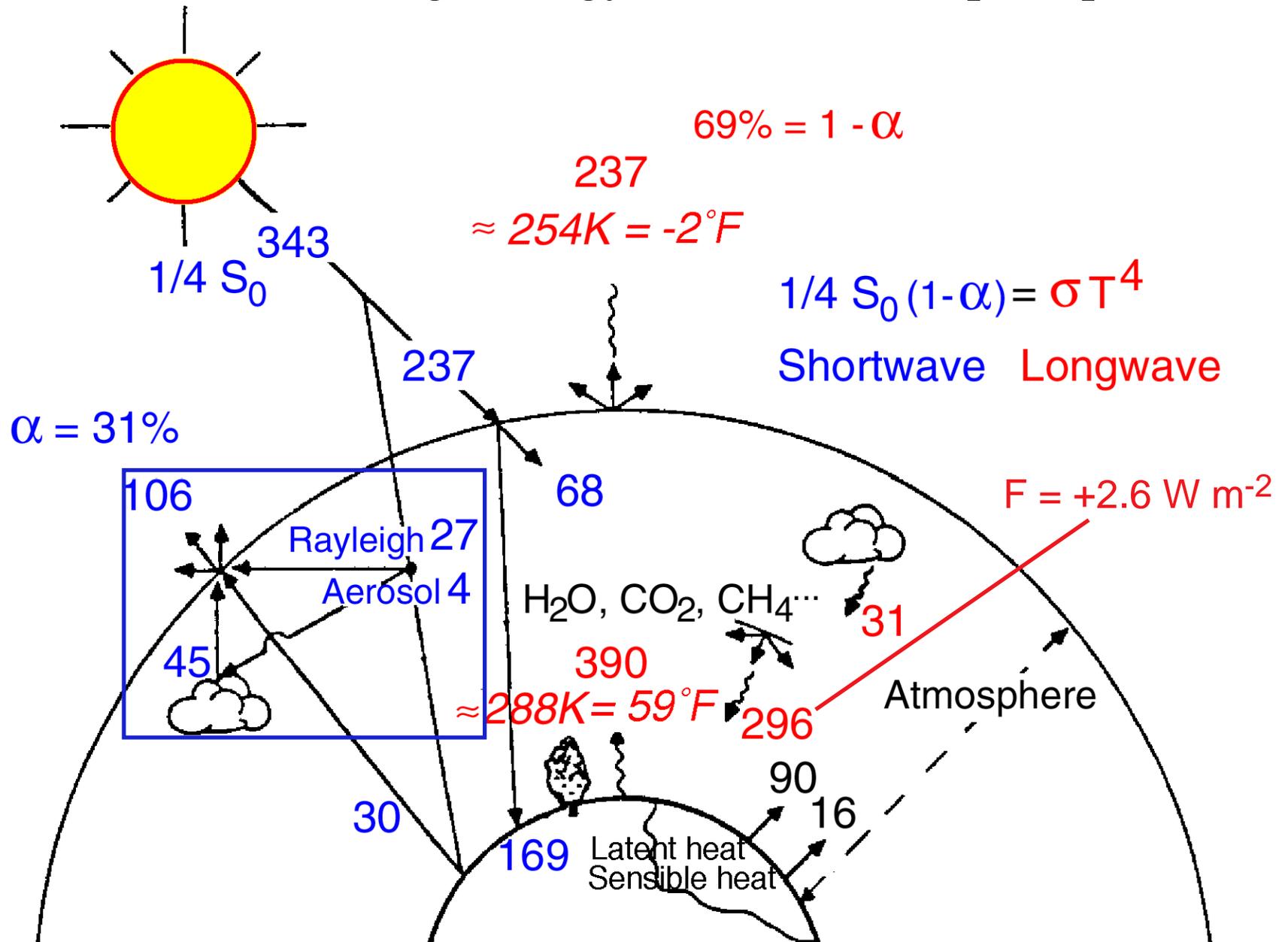
Concluding remarks

# The Greenhouse Effect



# GLOBAL ENERGY BALANCE

Global and annual average energy fluxes in watts per square meter



Schwartz, 1996, modified from Ramanathan, 1987

# ***ATMOSPHERIC RADIATION***

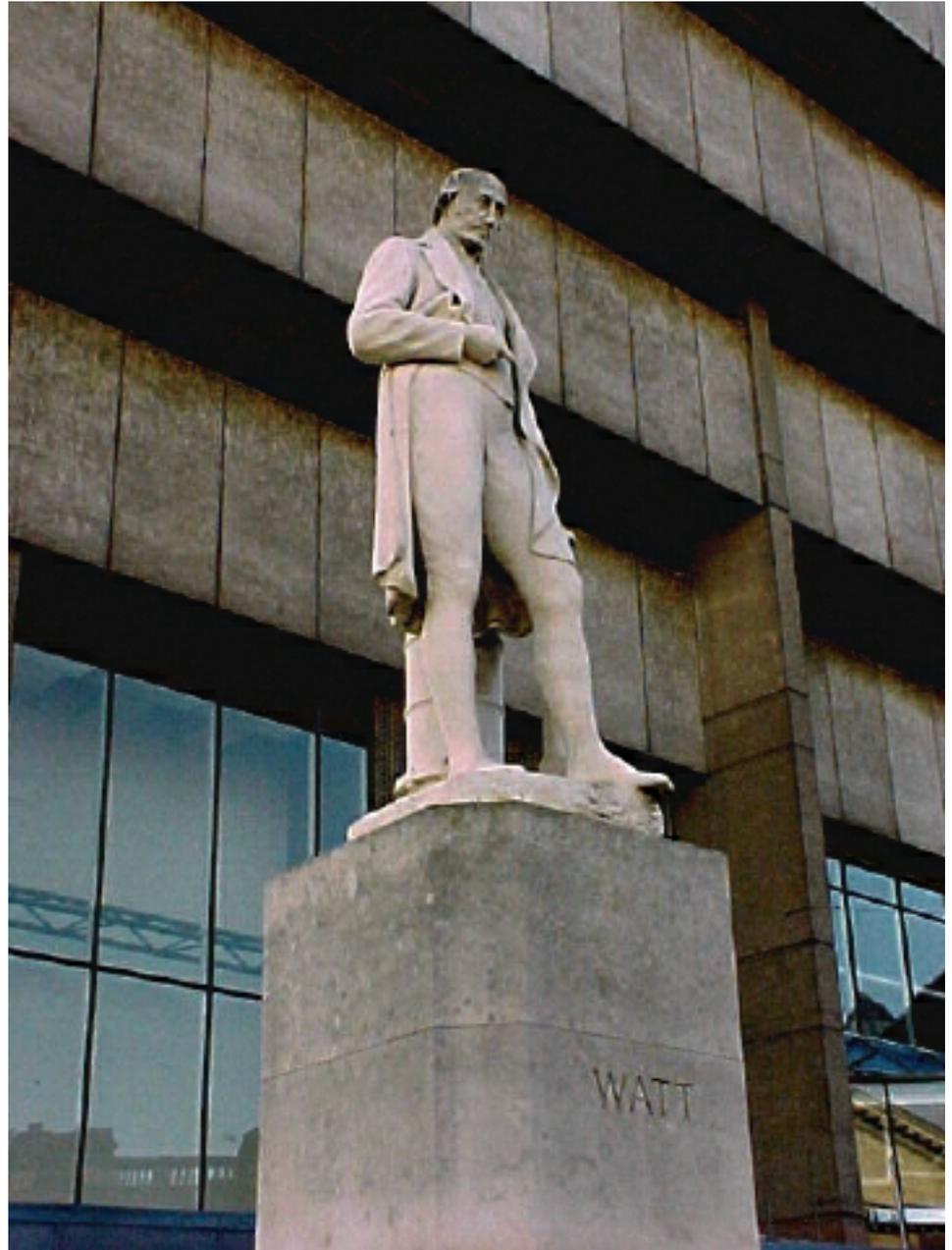
*Energy per area per  
time*

*Power per area*

*Unit:*

*Watt per square meter*

*$W m^{-2}$*



# ***RADIATIVE FORCING***

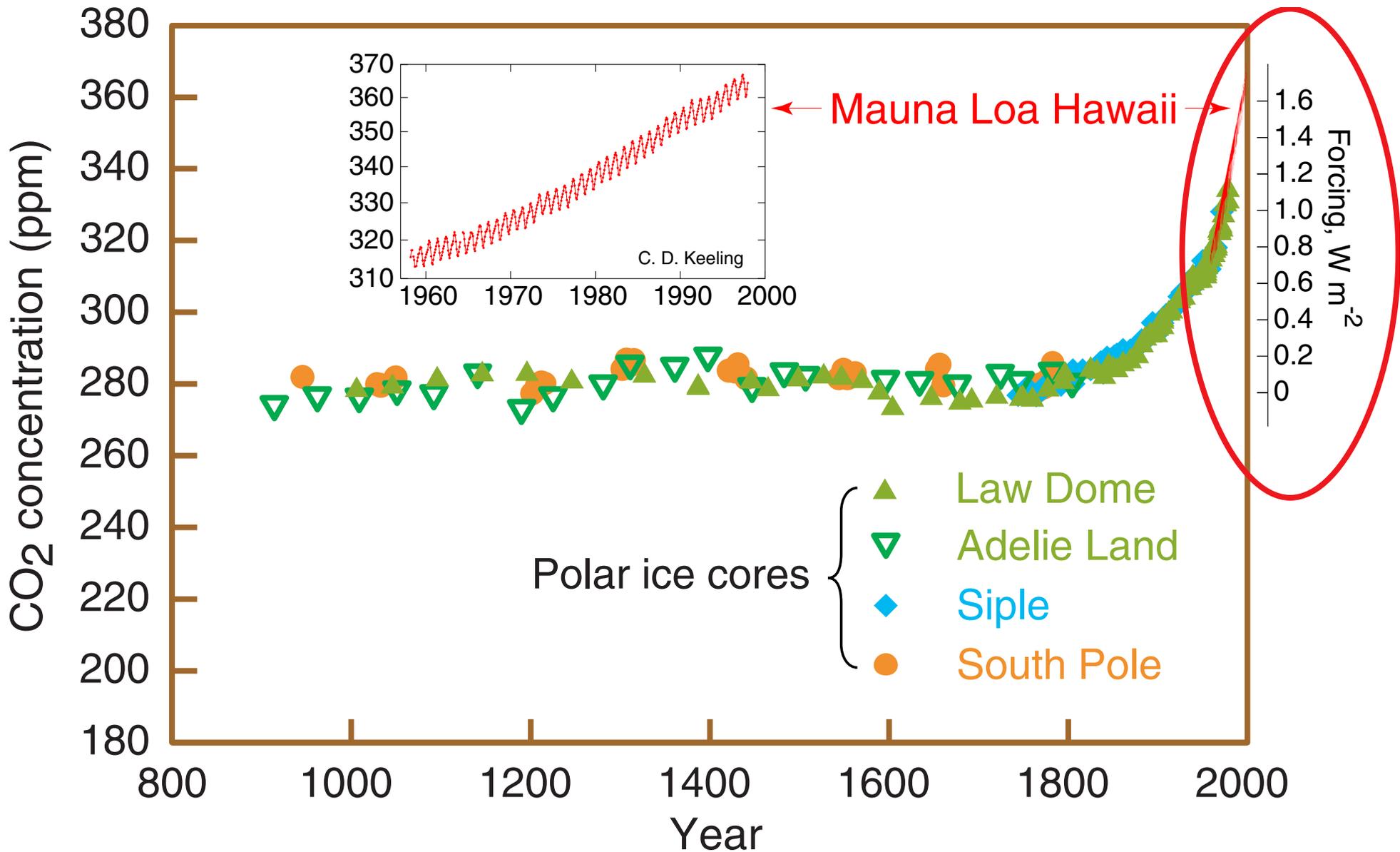
A *change* in a radiative flux term in Earth's radiation budget,  $\Delta F$ ,  $\text{W m}^{-2}$ .

## ***Working hypothesis:***

*On a global basis radiative forcings are additive and fungible.*

- This hypothesis is fundamental to the radiative forcing concept.
- This hypothesis underlies much of the assessment of climate change over the industrial period.

# ATMOSPHERIC CARBON DIOXIDE IS INCREASING

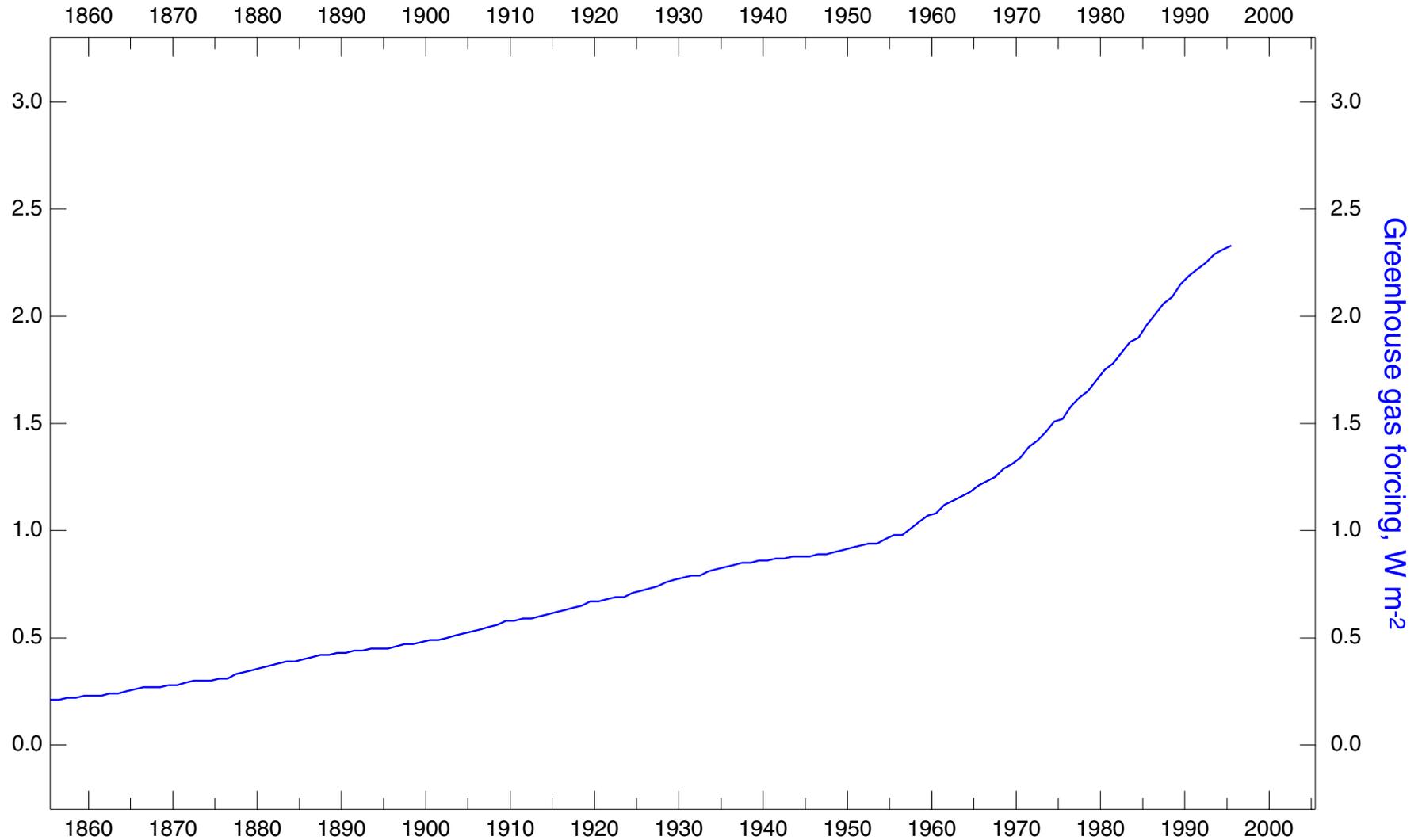


Global carbon dioxide concentration and infrared radiative forcing over the last thousand years

# CLIMATE FORCING AND RESPONSE

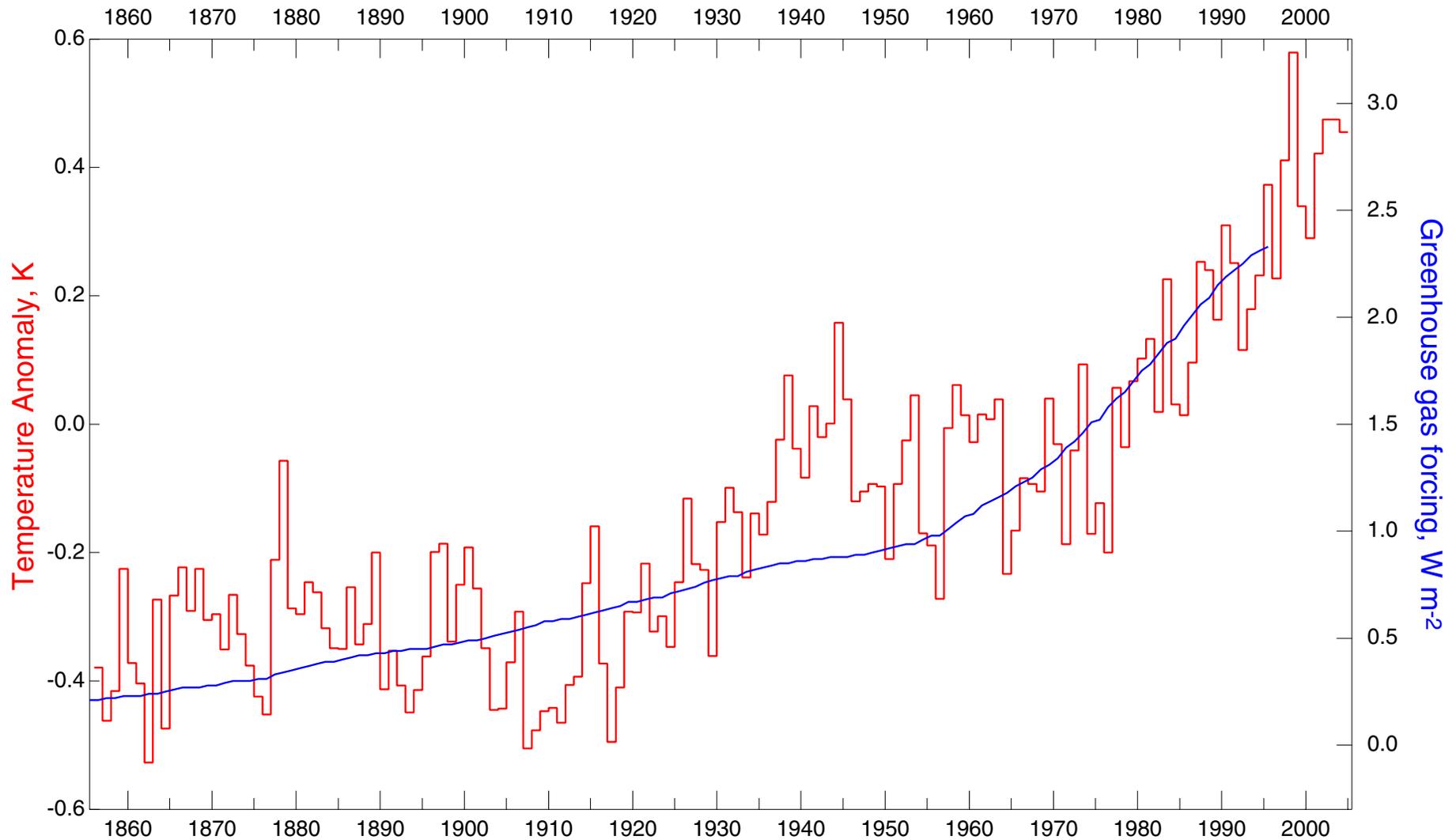
# GREENHOUSE GAS FORCING 1855-2004

Well mixed greenhouse gases: carbon dioxide, methane, nitrous oxide, CFC's



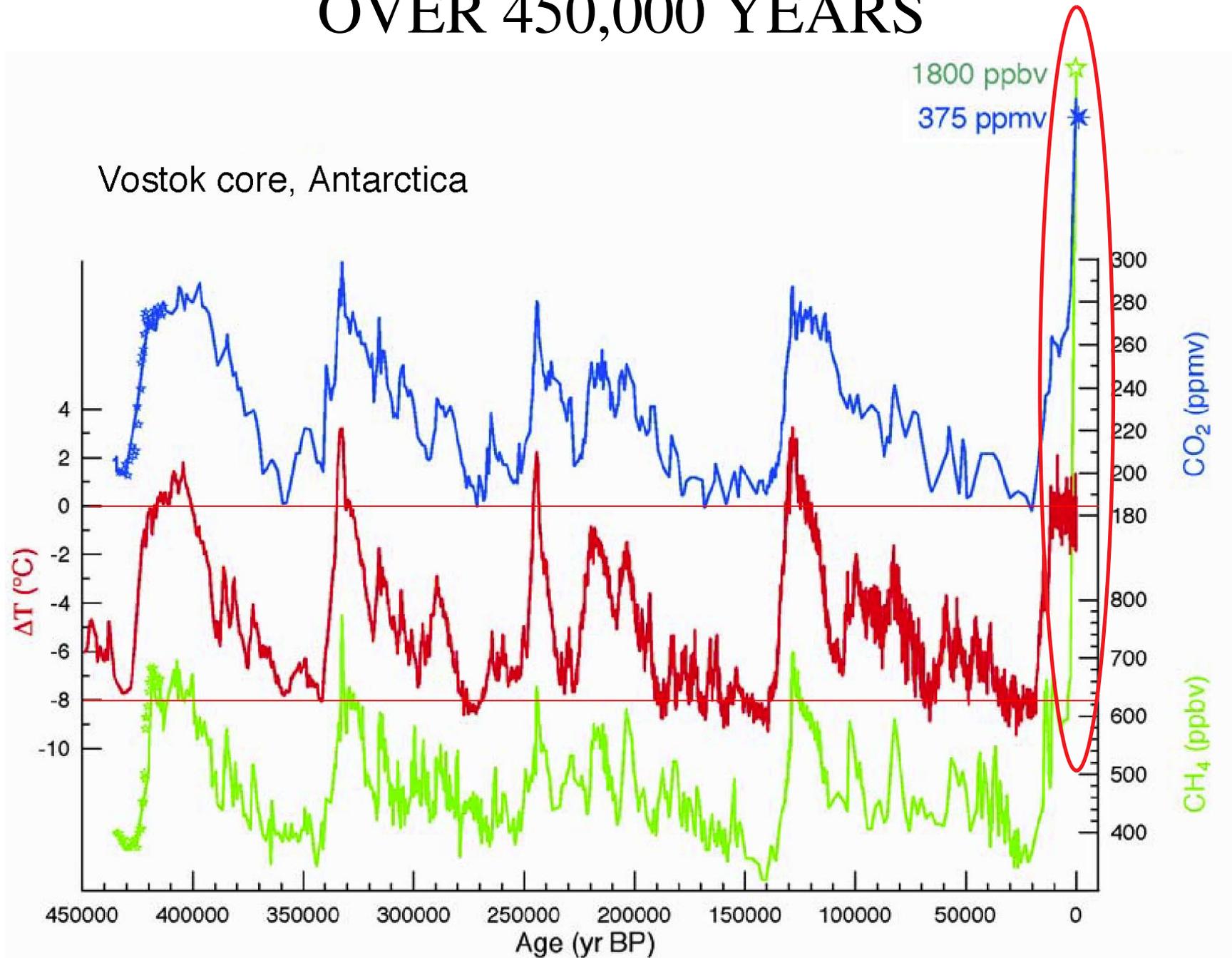
*IPCC, 2001*

# GREENHOUSE GAS FORCING AND CHANGE IN GLOBAL MEAN SURFACE TEMPERATURE 1855-2004



*IPCC, 2001; Climate Research Unit, University of East Anglia, UK*

# GREENHOUSE GASES AND TEMPERATURE OVER 450,000 YEARS



Modified from Petit et al., Nature, 1999

# ***CLIMATE RESPONSE***

The *change* in global and annual mean temperature,  $\Delta T$ , K, resulting from a given radiative forcing.

***Working hypothesis:***

*The change in global mean temperature is proportional to the forcing, but independent of its nature and spatial distribution.*

$$\Delta T = \lambda \Delta F$$

# *CLIMATE SENSITIVITY*

The *change* in global and annual mean temperature per unit forcing,  $\lambda$ , K/(W m<sup>-2</sup>),

$$\lambda = \Delta T / \Delta F.$$

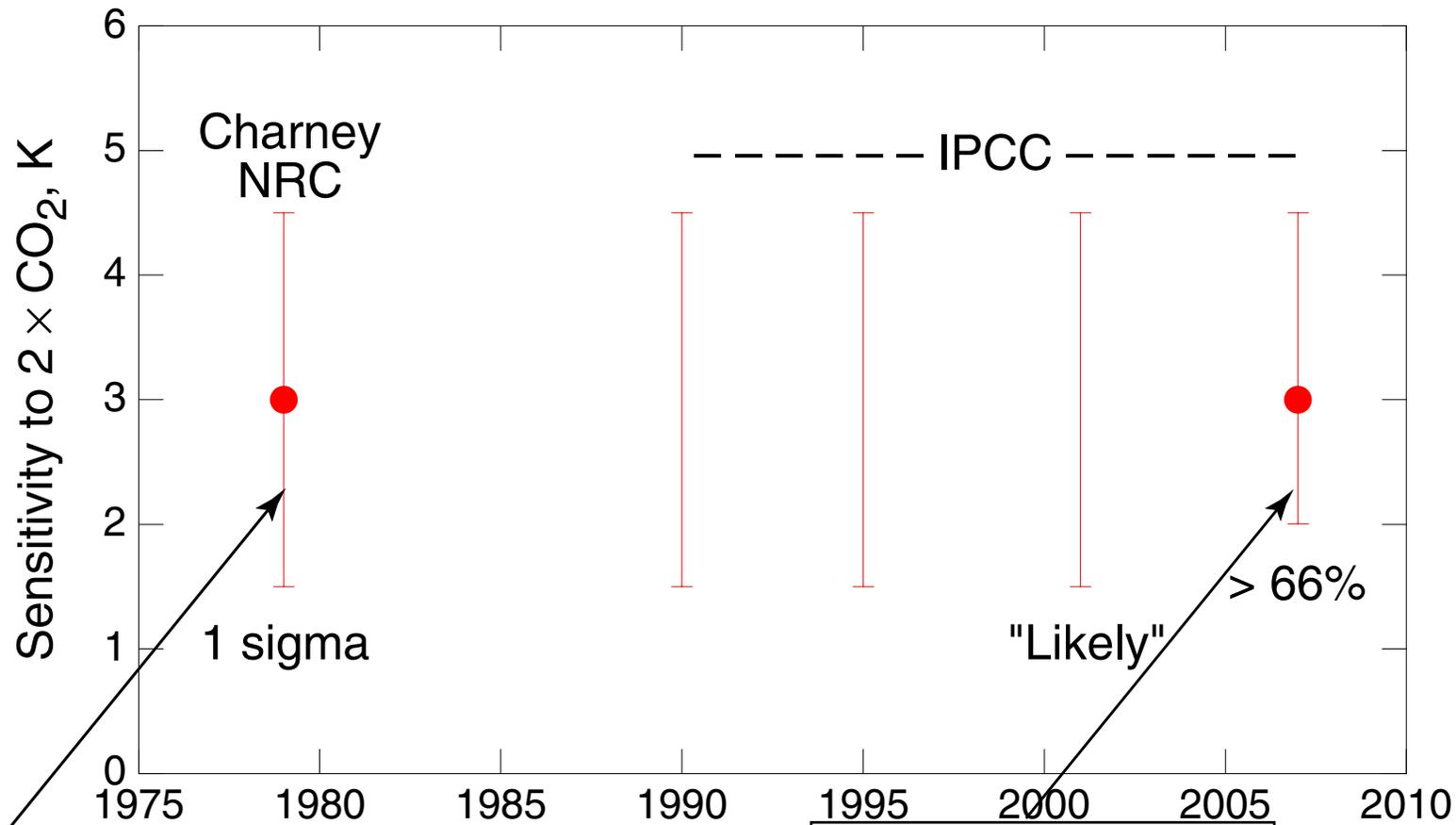
Climate sensitivity is not known and is the objective of much current research on climate change.

Climate sensitivity is often expressed as the temperature for doubled CO<sub>2</sub> concentration  $\Delta T_{2\times}$ .

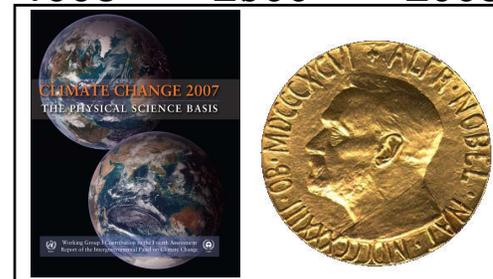
$$\Delta T_{2\times} = \lambda \Delta F_{2\times}$$

# CLIMATE SENSITIVITY ESTIMATES THROUGH THE AGES

Estimates of central value and uncertainty range from major national and international assessments



**Carbon Dioxide and Climate:  
A Scientific Assessment**  
NATIONAL ACADEMY OF SCIENCES  
Washington, D.C. 1979



Despite extensive research, climate sensitivity remains *highly uncertain*.

# *IMPLICATIONS OF UNCERTAINTY IN CLIMATE SENSITIVITY*

Uncertainty in climate sensitivity translates directly into . . .

- Uncertainty in the amount of *incremental atmospheric CO<sub>2</sub>* that would result in a given increase in global mean surface temperature.
- Uncertainty in the amount of *fossil fuel carbon* that can be combusted consonant with a given climate effect.

*At present this uncertainty is about a factor of 3.*

# ***KEY APPROACHES TO DETERMINING CLIMATE SENSITIVITY***

- Paleoclimate studies.
- Empirical, from climate change over the instrumental record.
- Climate modeling.

***Climate models evaluated by comparison with observations are essential to informed decision making.***

# ***IMPORTANCE OF KNOWLEDGE OF CLIMATE TO INFORMED DECISION MAKING***

- The lifetime of incremental atmospheric CO<sub>2</sub> is about 100 years.
- The expected life of a new coal-fired power plant is 50 to 75 years.

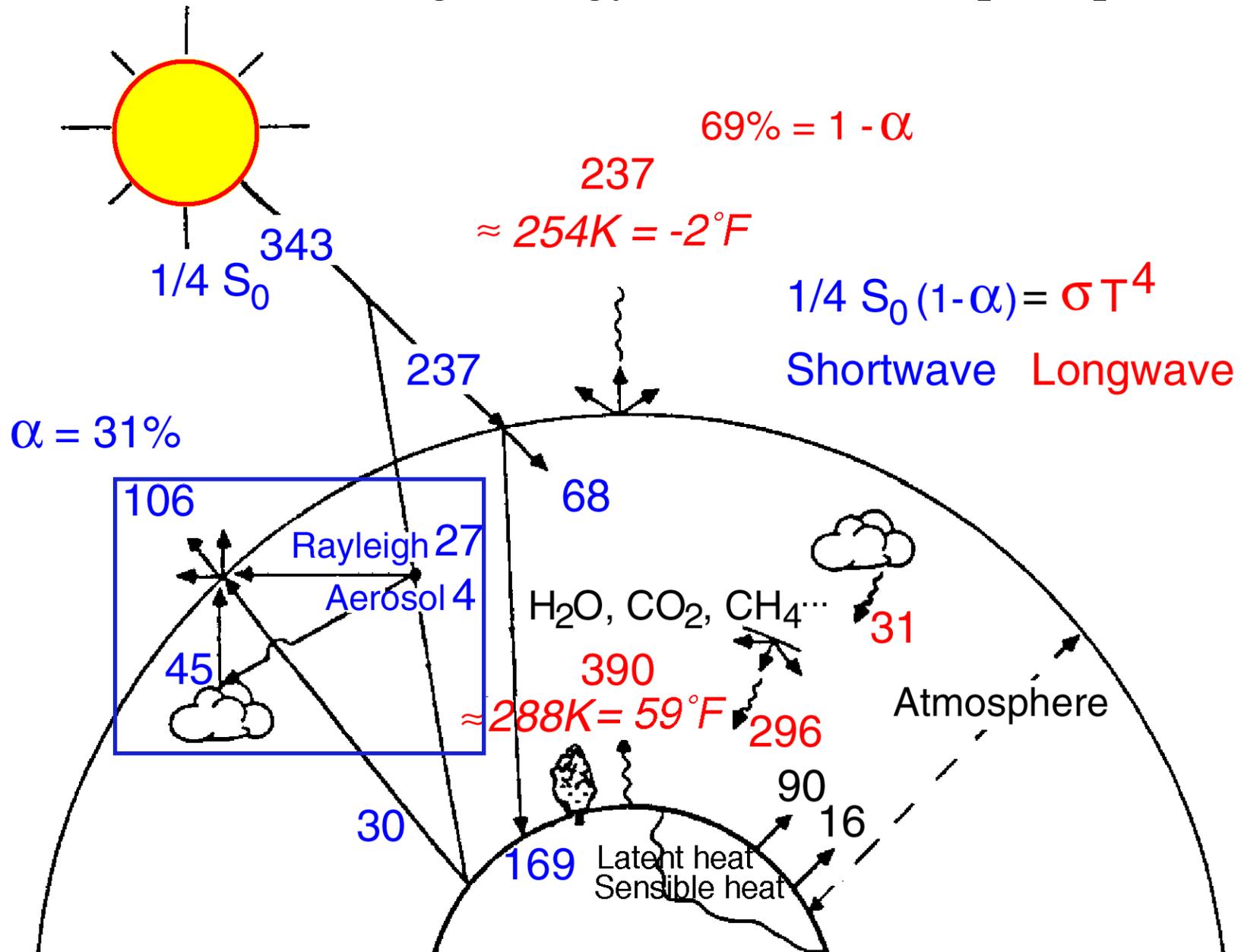
***Actions taken today will have long-lasting effects.***

***Early knowledge of climate sensitivity can result in huge averted costs.***

# INFLUENCE OF AEROSOLS

# GLOBAL ENERGY BALANCE

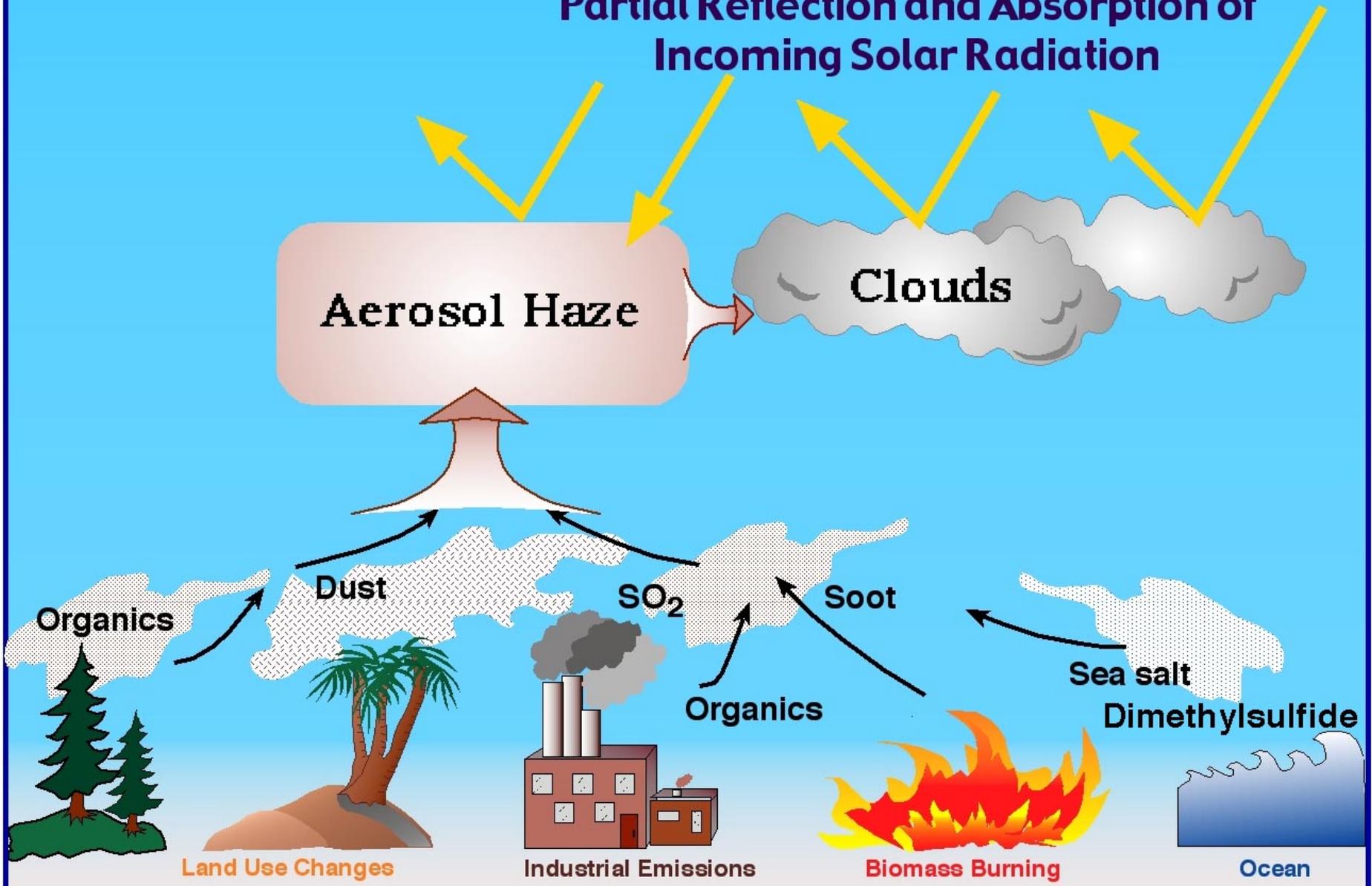
Global and annual average energy fluxes in watts per square meter



Schwartz, 1996, modified from Ramanathan, 1987

# Radiative Forcing by Tropospheric Aerosol

Partial Reflection and Absorption of Incoming Solar Radiation



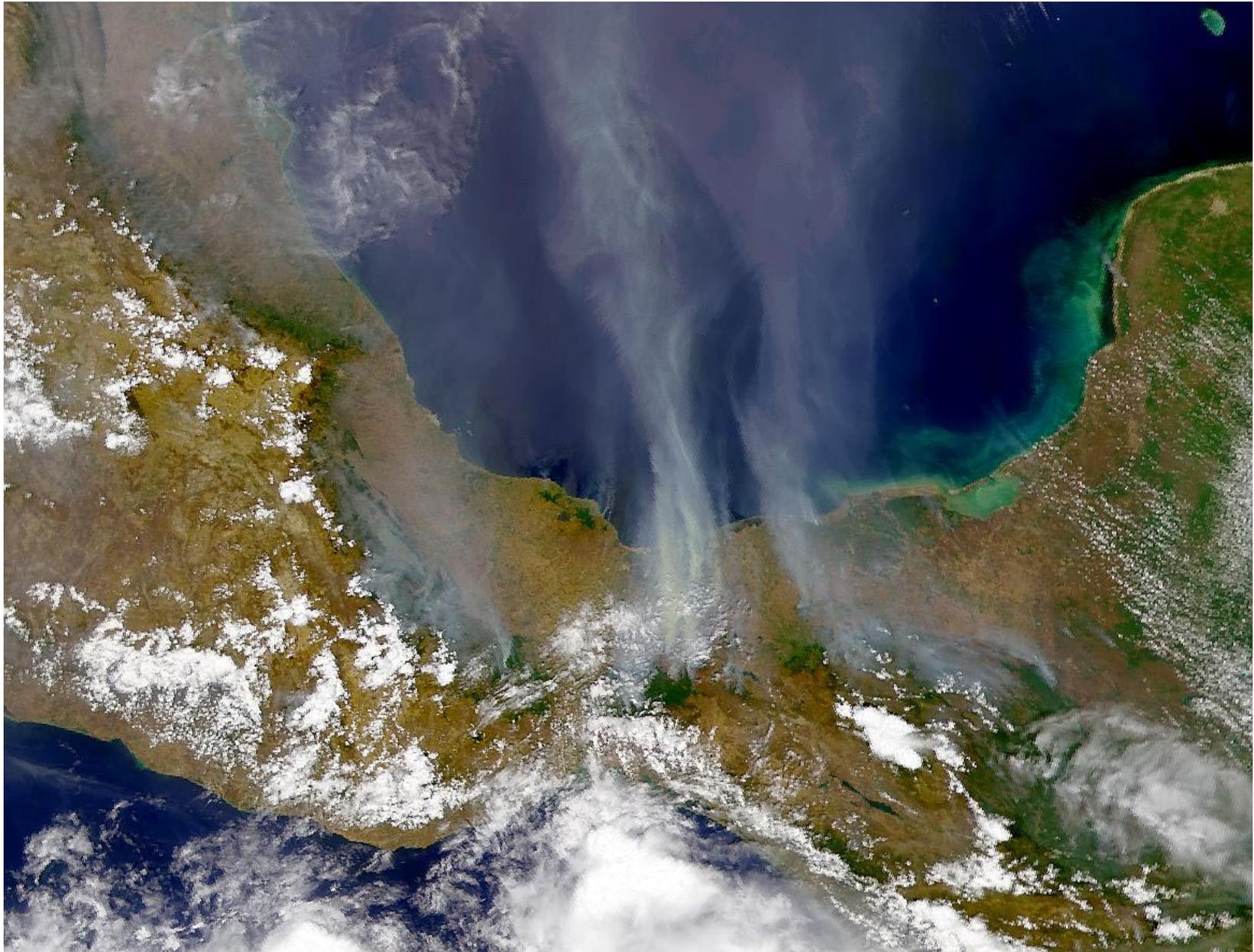


# AEROSOL IN MEXICO CITY BASIN



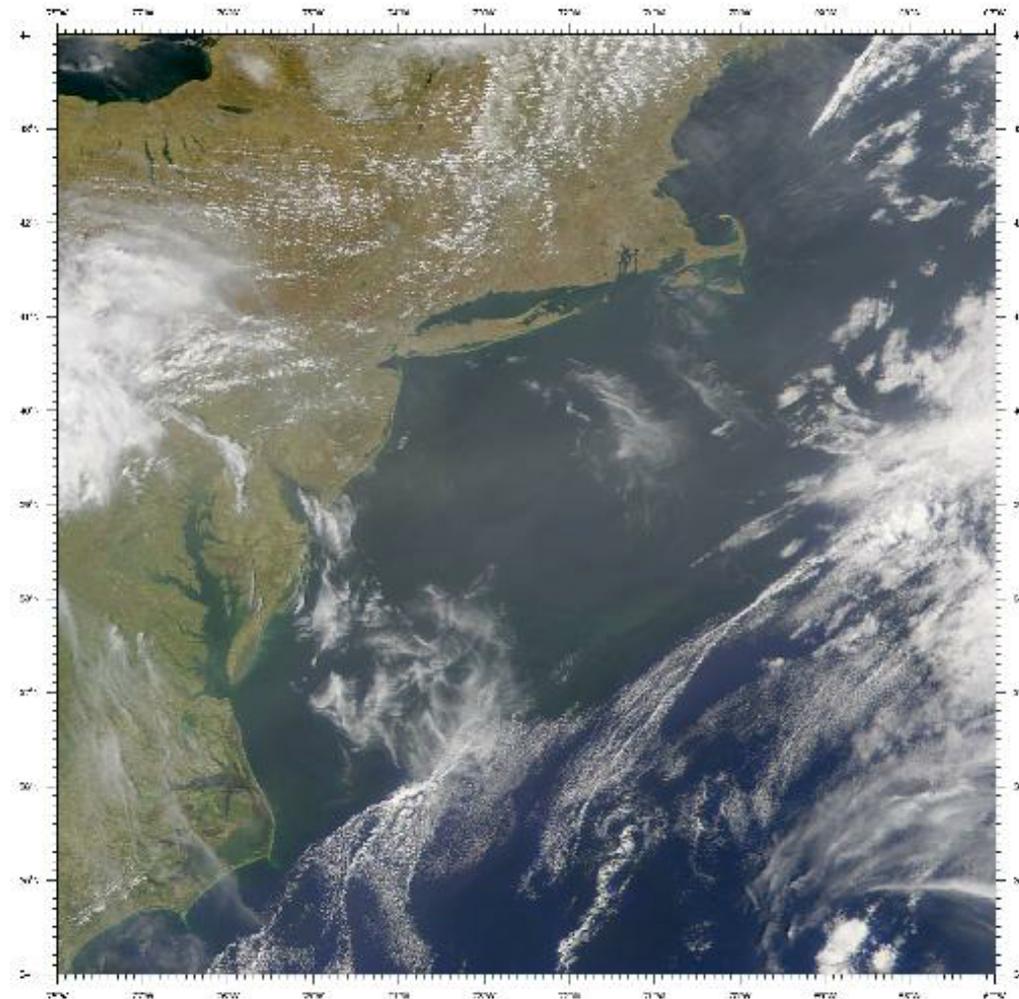
Mexico City is a wonderful place to study aerosol properties and evolution.

# AEROSOLS AS SEEN FROM SPACE



Fire plumes from southern Mexico transported north into Gulf of Mexico.

# AEROSOL: A suspension of particles in air

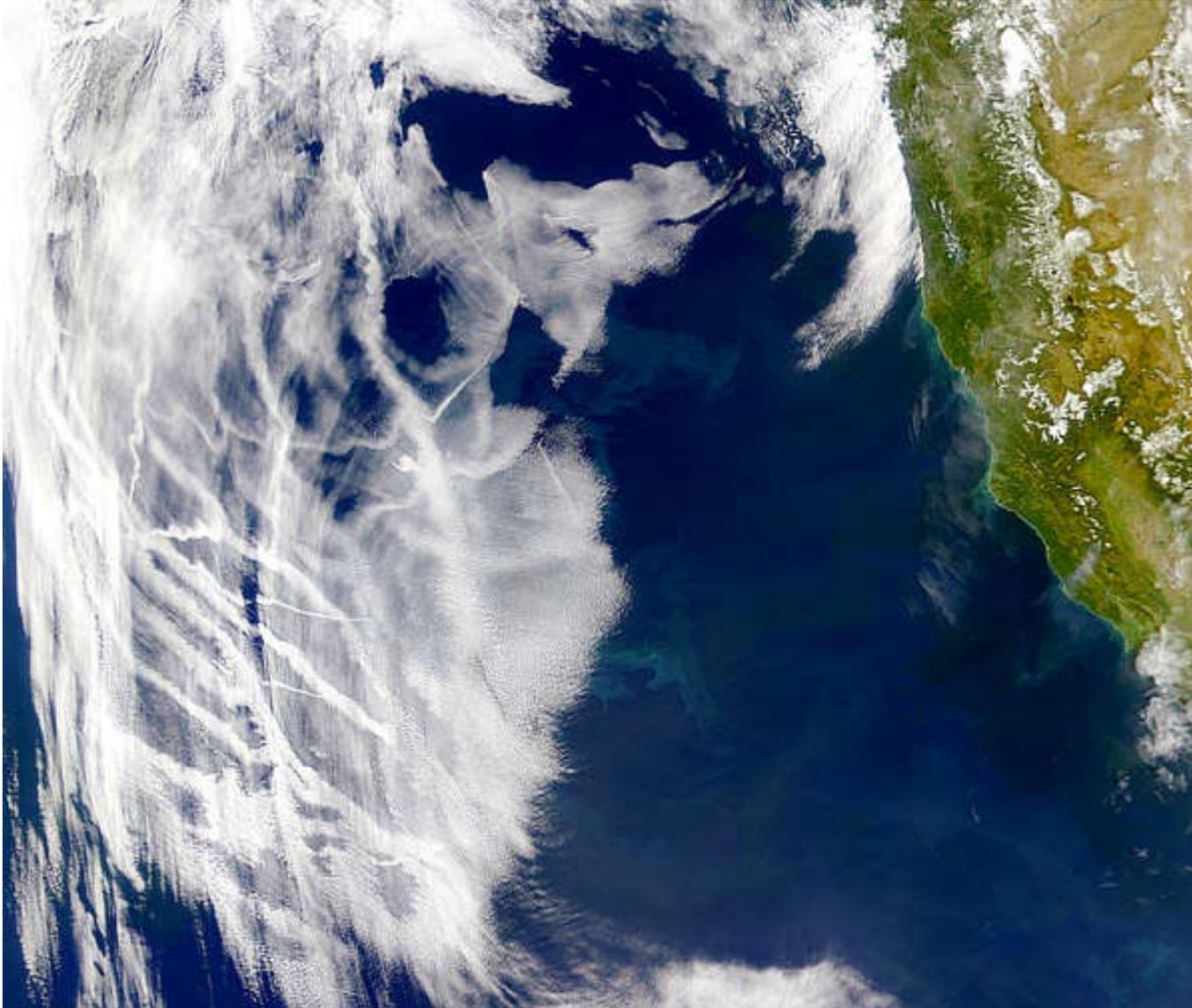


*2001-04-22-17:28  
SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE*

Atmospheric aerosols may result from primary emissions (dust, smoke) or from gas to particle conversion in the atmosphere (haze, smog).

# CLOUD BRIGHTENING BY SHIP TRACKS

Satellite photo off California coast

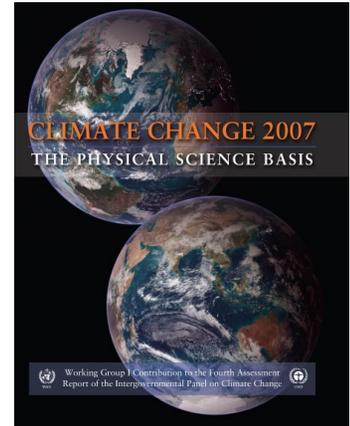
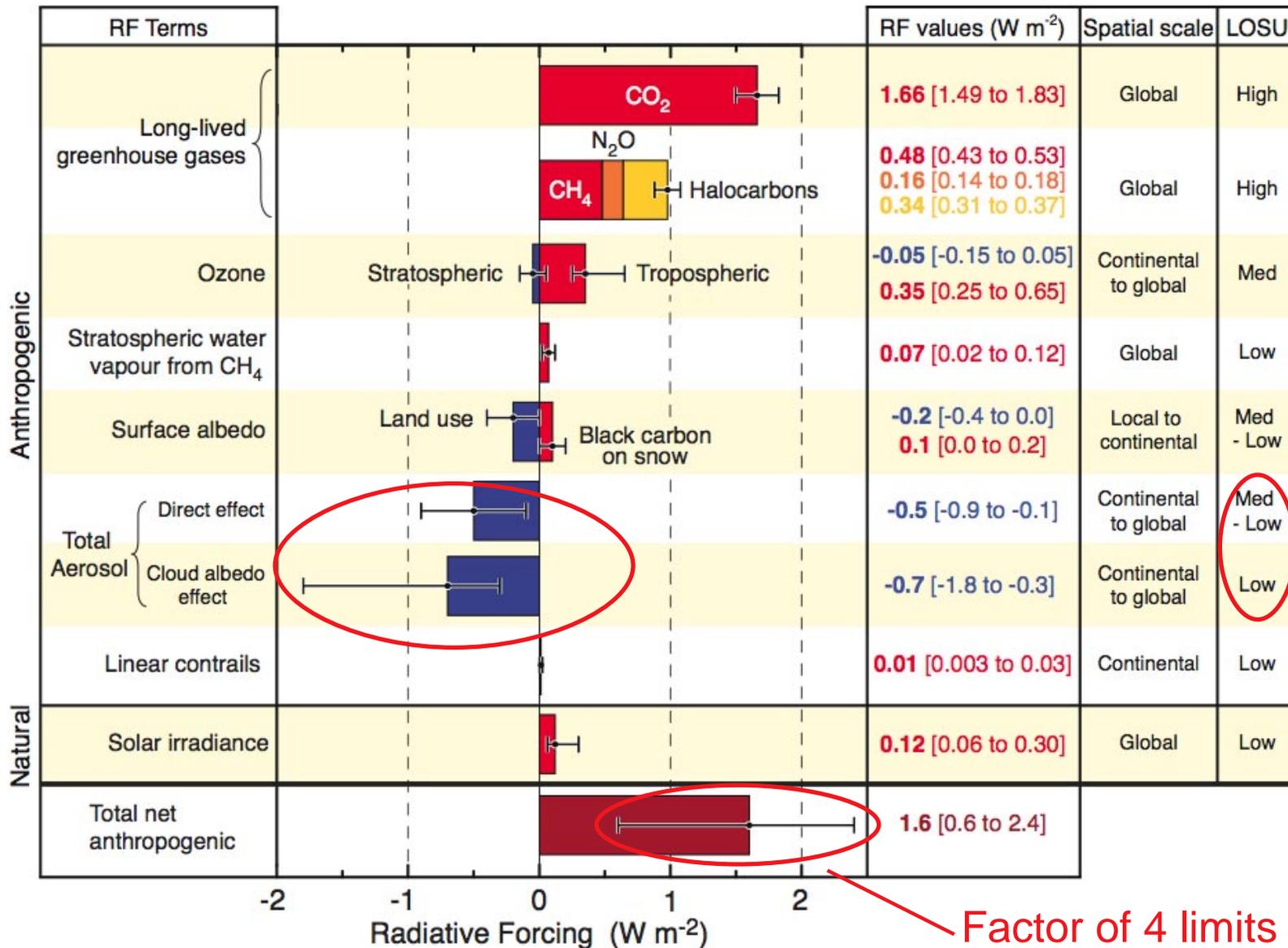


Aerosols from ship emissions enhance reflectivity of marine stratus.

# UNCERTAINTY IN CLIMATE FORCING

# GLOBAL-MEAN RADIATIVE FORCINGS (RF)

Pre-industrial to present (Intergovernmental Panel on Climate Change, 2007)



©IPCC 2007: WG1-AR4

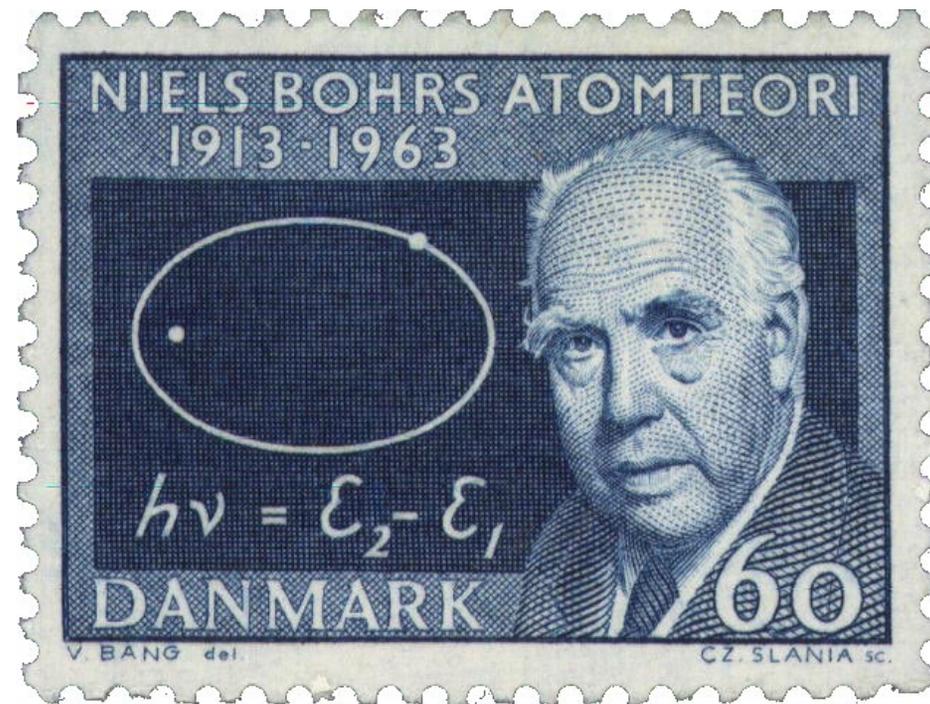
Factor of 4 limits empirical inferences and model evaluation.

LOSU denotes level of scientific understanding.

*Looking to the  
Future . . .*

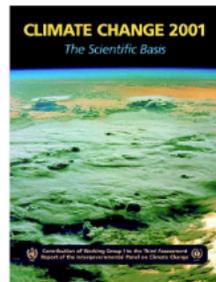
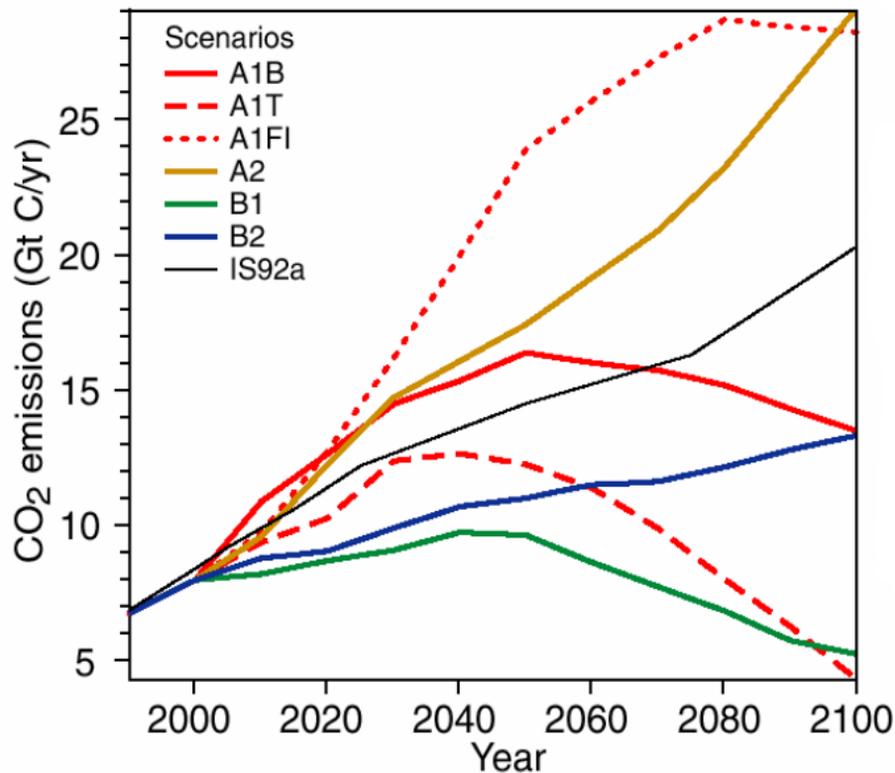


*Prediction is difficult,  
especially about the future.*

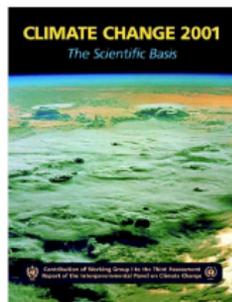
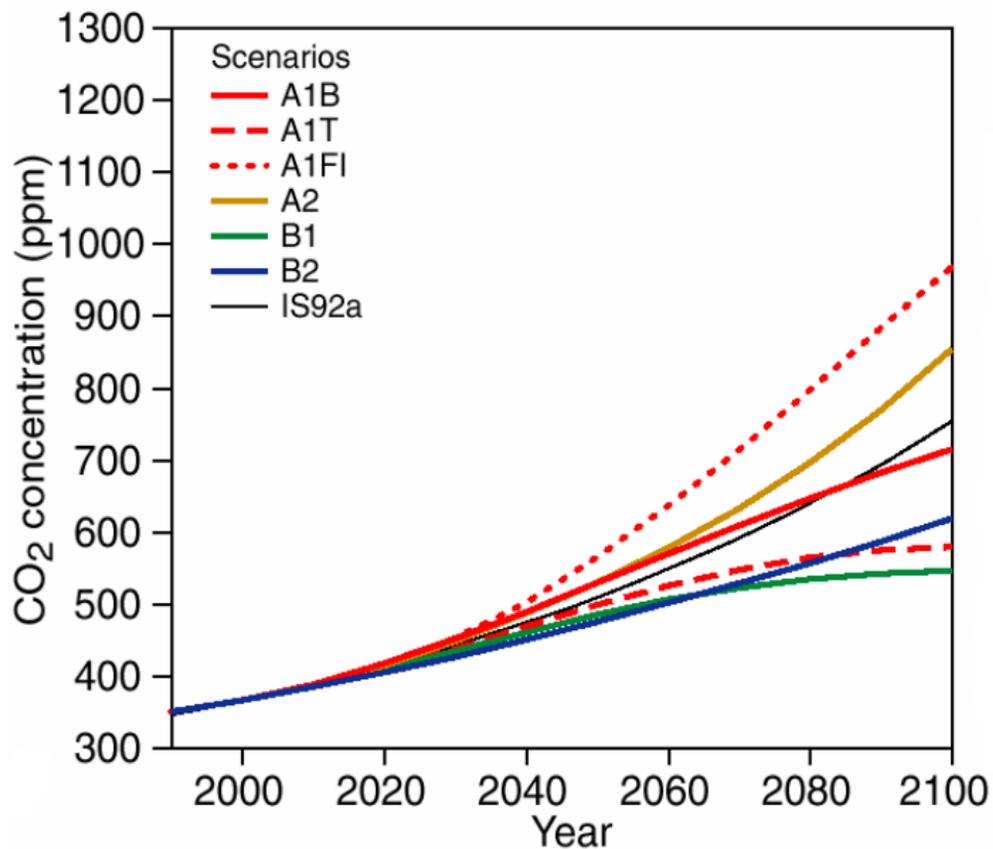


*– Niels Bohr*

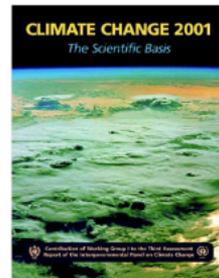
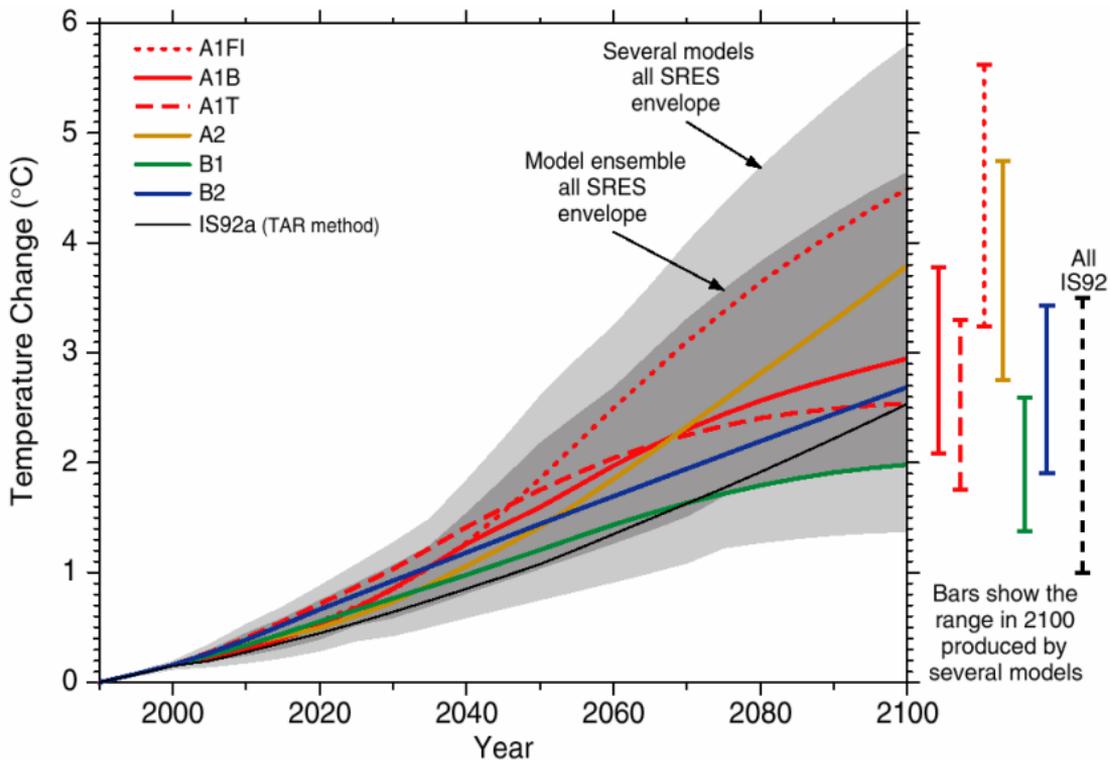
# PROJECTIONS OF FUTURE CO<sub>2</sub> EMISSIONS



# PROJECTIONS OF FUTURE CO<sub>2</sub> CONCENTRATIONS



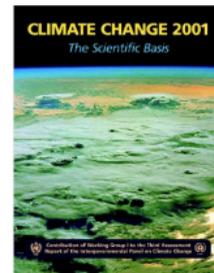
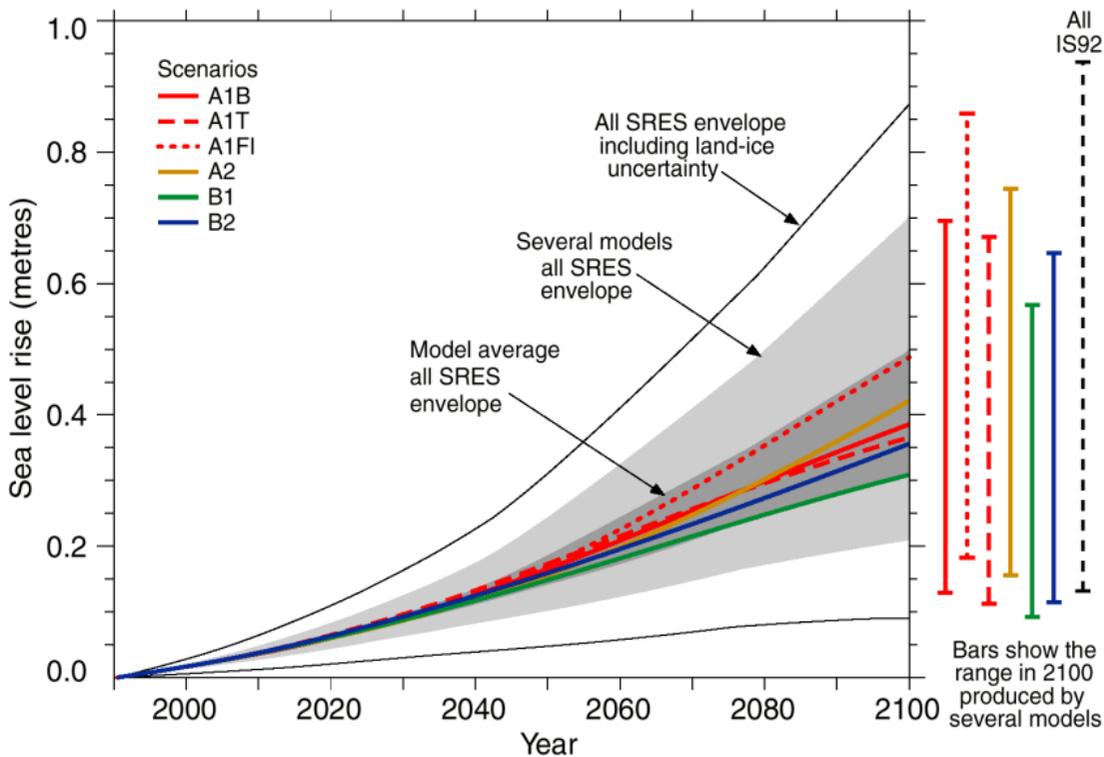
# PROJECTIONS OF FUTURE TEMPERATURE CHANGE



Bars show the range in 2100 produced by several models

# PROJECTIONS OF FUTURE SEA LEVEL RISE

## Thermosteric (density change) only





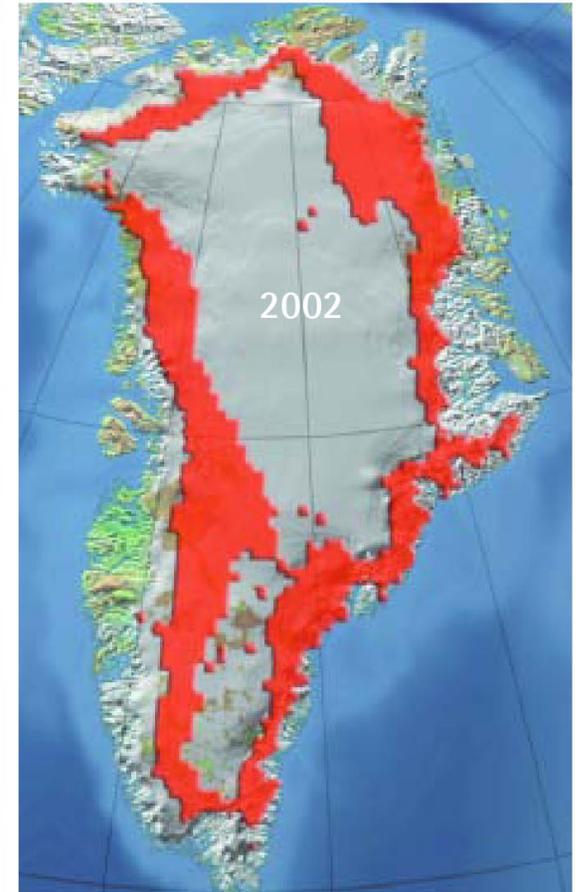
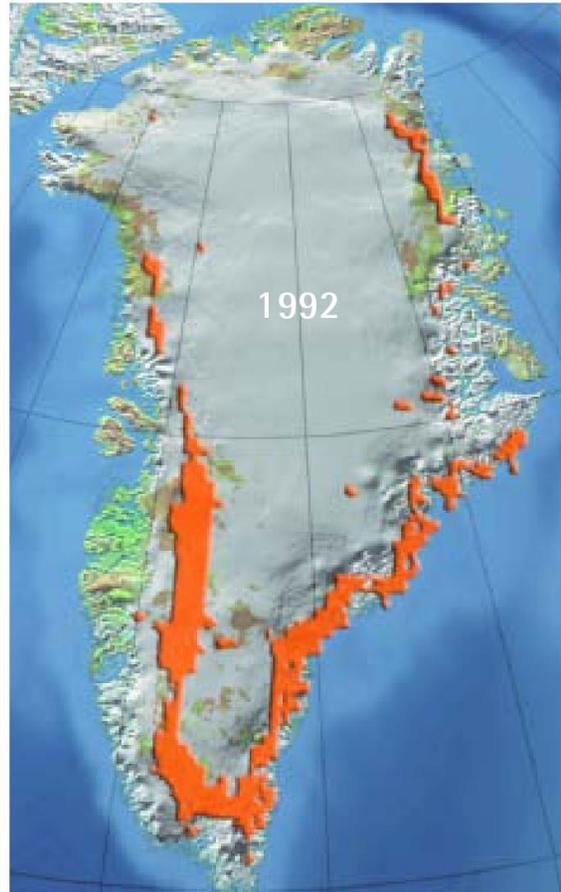


# MELTING OF GREENLAND ICE CAP

Satellite determination of extent of glacial ice 1992 vs 2002



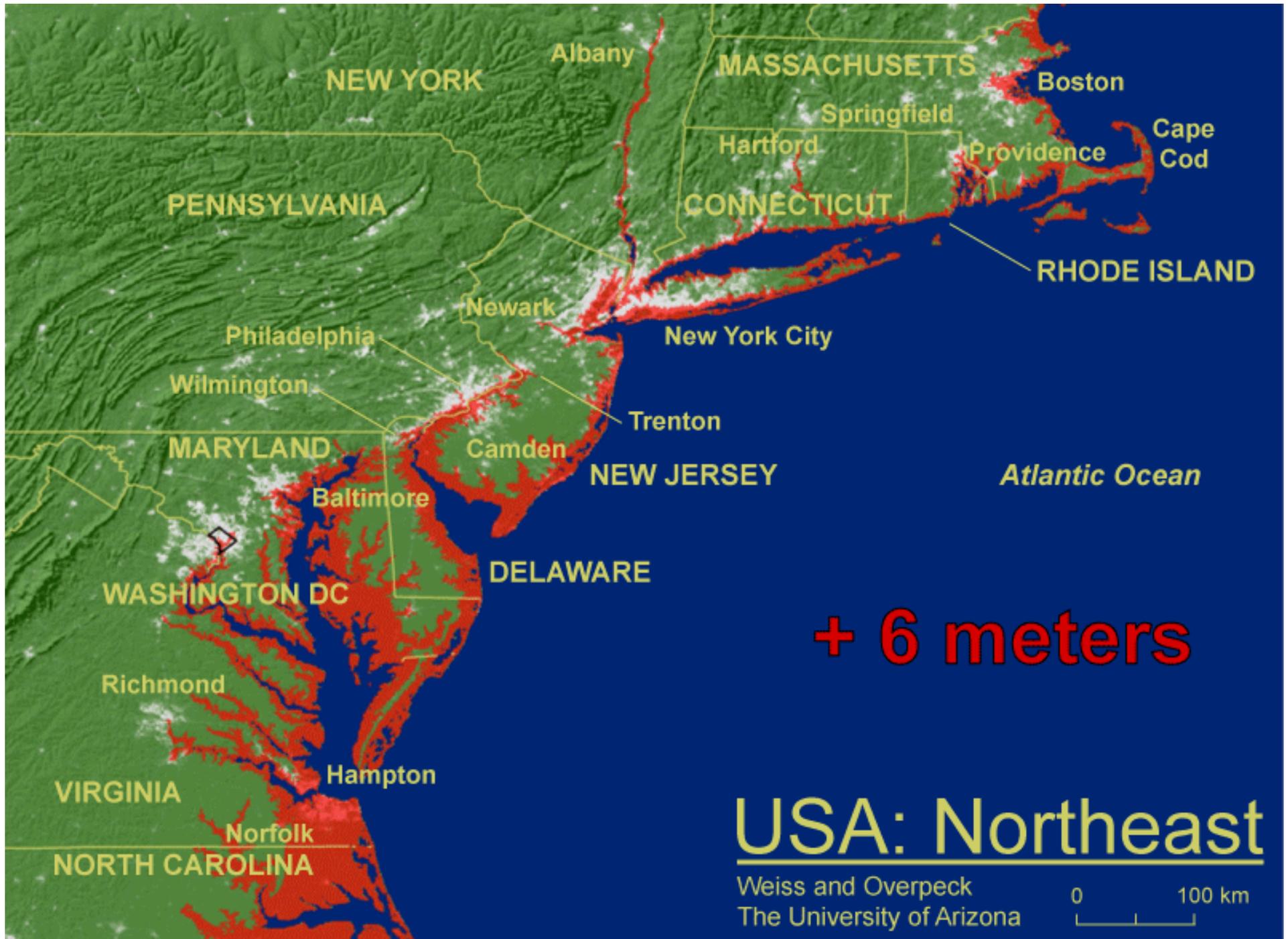
NASA



*Arctic Climate Impact Assessment, Cambridge, 2004*

Complete melt of the Greenland ice sheet would raise the level of the global ocean 7 meters.







*"Gentlemen, it's time we gave some serious thought  
to the effects of global warming."*

# CONCLUDING REMARKS

Atmospheric carbon dioxide will continue to increase absent major changes in the world's energy economy.

The consequences of this increase are not well known but they range from *serious* to *severe* to *catastrophic*.

Uncertainty in forcing by aerosols greatly limits present understanding of climate change.

Present scientific understanding is sufficient to permit “no regrets” decision making.

Research is urgently needed to refine “what if” projections.

Actions taken (or not taken) today will inevitably affect future generations.